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Impact of V2G integration on an urban feeder in Nepal: A case of Baneshwor feeder

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ABSTRACT:

The increasing number of electric vehicles increases strain on distribution system. Voltage, Power loss and reliability of the system deteriorates. During peak load charging of these vehicle, stability of the system will more degrade. This paper proposes V2G control scheme. A coordinated way of charging and discharging of EV. The vehicles are charging during off-peak hour when tariff rate is low and discharge during peak hour when tariff rate is high. The penetration of V2G increased system performance. The impact of Fast charging station is also considered. It is assumed that charging station operates whole day. A smart charging control is considered for V2G scheme. The charging station is placed using a novel reliability index approach called Electric Vehicle Placement Index (EVPI). Genetic Algorithm is used for optimal placement of CS. The thesis aims to decrease the peak load demand and increase the reliability of the system. The analysis is carried out in IEEE 33 bus radial system and then implemented on real-time Baneshwor feeder distribution system.

KEYWORDS: *Electric Vehicle (EV), Charging Station (CS), Distribution system, Electric Vehicle Placement index (EVPI), Vehicle-to-Grid (V2G), Reliability.*

I. INTRODUCTION

The recent trend of Electric Vehicles (EVs) is a transformative shift in the automotive industry. The rapid advancement of battery technologies, and power control system has significantly improved the performance, range, and affordability of Electric Vehicles. EVs helps in controlling air pollution in urban area. According to Bloomberg, Sales of EV cars may increase to 28 million in 2030 and 54 million by 2040 [1]. Nepal has targeted 35% share of EV in transportation [2]. There are only 3800 vehicles registered in Kathmandu by July,2023 mostly due to covid-19 pandemic [3]. By 2030, Nepal has targeted sales of EV increases to cover 90% market of all private EV sales [1]. Large number of EV increases strain on distribution network. Voltage and Reliability of the system decreases. Power loss in the system increases. During peak load time, it is very difficult to provide charging to these vehicles. Although there is sufficient power supply, But due to limited conductor capacity. There is chance of conductor failure, multiple interruption. Real-Time charging management is required not to degrade voltage, reliability efficiency and economics of the electricity services [4].

This paper proposes V2G control scheme into the power system to provide real-time management of charging and discharging. During peak hour, V2G enable the supply of electricity at charging points [5]. Electric vehicle can be effectively used as energy storage device [6]. Discharging to grid increase efficiency and performance of the network. It provides spinning reserve for instantaneous intermittency [7]. Discharging in peak hour is also cost benefit [6]. The price of electricity is high during peak hour and low during off peak hour. Charging EV during off-peak hour and discharging during peak hour. Charging is managed to lesser the impact on the grid and maximize the profit [6]. At present the number of EV is very small, the power system is not affected. When it increases by large number in future will have highly affect the power system [8]. Inversely, when discharge takes by these vehicles will increase the reliability of power system. EV affect the distribution system. Reliability assessment of distribution is determined. Reliability is evaluated when charging is unscheduled and scheduled discharging V2G mode. The effect of V2G can be clearly seen in the distribution system with the increasing penetration of EVs [8]. Very few studies are conducted on evaluating the impact of V2G on urban distribution system. Some assumptions have been made. Charger used for charging is bidirectional. It's maximum charging and discharging rate is same. Vehicle is distributed according to number of consumers in distribution center. Minimum and maximum SOC of vehicle is 20% and 90%. It is assumed that vehicle would travel 50Km per day. The vehicle mainly travels distance between office and home. Two types of vehicles are considered Tata Nexon and BYD. EVs controlled charging in a reliability analysis tends to be probabilistic, i.e., multiple charging scenario is developed and utilized over the reliability assessment time horizon (hourly basis).

The placement of charging station increases additional strain on the grid infrastructure [9]. To minimize its impact, it should optimally place. Many researches are conducted for optimal placement of charging station. I have used A novel Electric vehicle placement index (EVPI) approach for CS allocation. Charging station is placed in stronger bus. Bus with high voltage profile is strong bus when a single parameter is considered [10]. For various parameter, effect of EV charging load is carried out in [11]. This approach gives more priority to reliability. Impact of CS with reliability index-based approach on urban distribution network is analysis in [12]. With this approach, CS is placed In IEEE 33 bus system with different test cases and then validated on a real-time Baneshwor distribution system in Kathmandu. The mathematical formulation and weightage to the objective function is developed using [13]. Load in the charging is varying throught the day [14-15]. It is peak at 11 am and low at night time.

The paper is organized in six sections as follows: Section II covers the mathematical formulation of reliability indices. Section III illustrates novel based approach on the reliability index for placing the CS. This section also deals with mathematical formulation of EVPI. Section IV explains about V2G control strategy. Design framework for V2G scheduling. It is directly applied to the Baneshwor feeder. Section V shows the results on the impact in distribution after placing CS and implementing V2G. Finally, section VI presents conclusion of the work.

II. RELIABILITY OF DISTRIBUTION NETWORK

Reliability is the probability of a system that it performs satisfactorily for the period of time under the set of operating conditions. Reliability of the distribution network closely related to the satisfaction level of customers. There are two methods of finding reliability Sequential Monte-Carlo (SMC) and non-sequential Monte-Carlo (NSMC). In sequential method, simulation proceeds for dynamic systems, time-series data, and situations where new information arrives sequentially. In non-Sequential method simulation are more versatile, applicable to a broader range of problems, and often simpler to implement simulation method is adopted for this thesis. The states are sampled proportional to their probabilities. This method is very powerful tool used to solve complex differential equations [16]. Bus data, Line data and outage data of IEE-33 Bus system data is taken from [9]. Distribution system reliability is a crucial aspect of power delivery, ensuring continuous and quality electricity supply to consumers. The literature reveals various reliability indices, such as System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), and Customer Average Interruption Duration Index (CAIDI), which are commonly used to assess the performance and reliability of distribution systems. Studies have emphasized the importance of improving these indices to meet the increasing demand for reliable power supply.

For evaluation of the reliability indices of the distribution network, data of failure rate (λ_j), repair rate (μ), average outage duration rate (U_j), and number of consumers of the buses of the distribution network (N_i) is taken from the reference paper no.

$$SAIFI = \frac{\sum \lambda_j N_j}{\sum N_j} \quad (1)$$

$$SAIDI = \frac{\sum U_j N_j}{\sum N_j} \quad (2)$$

$$CAIDI = \frac{\sum U_j N_j}{\sum \lambda_j N_j} \quad (3)$$

$$ENS = \sum L_j U_j \quad (4)$$

$$AENS = \frac{L_j U_j}{\sum N_j} \quad (5)$$

SAIFI is System Average Interruption Frequency Index that defines number of times a system customer experiences interruption during a particular time. It illustrates the condition of the system in terms of interruption. SAIDI is System Average Interruption Duration Index that defines Average interruption duration per customer served. It illustrates the condition of the system in terms of duration of interruption. CAIDI is Customer Average Interruption Duration Index that defines Average interruption duration time for those customers interrupted during a year. It illustrates average outage duration that any given customer would experience. ENS is energy not supplied gives the total energy not supplied by the system. It illustrates an indicator of energy deficiency of the system. AENS is Average Energy Not Supplied regarded as the average system load curtailment index. It gives an idea of how much energy is not served during particular time period.

III. OPTIMAL PLACEMENT OF CHARGING STATION

A heavy work to find the optimal placement of CS [17]-[19]. Before deciding where to allocate charging stations, it's crucial to understand the reliability of the existing electrical distribution network. BRI helps assess the reliability of individual components within this network. Components with low BRI values are more prone to failures and may need infrastructure upgrades or additional backup power sources, which could influence the allocation of charging stations.

$$BRI = \frac{AIT_i}{max_{jB}\{AIT_j\}} \quad (6)$$

Where AITi is the average interruption time of the ith bus, B is the total count of buses in the system, and j denotes the bus with maximal AIT.

AIT of the ith bus is evaluated as

$$AIT = \lambda i \cdot Ui \quad (7)$$

Where λi and Ui are the average failure rate and average outage duration of the ith bus. The bus with the smallest BRI value is designated as a strong bus.

The effect of charging loads in power system is analysis by the severity level of EVPI. EVPI gives threshold limit of loading without adversely affecting the distribution network parameters. The mathematical expression of the EVPI is in (18)

$$EVPI = W_{VSI} * A + W_{RI} * B + W_{LSF} * C. \quad (8)$$

Where W_{VSI}, W_R, and W_{LSF} are the weights to VSI, reliability and LSF respectively. Voltage stability index is calculated by Eminoglu et al. [20]. *A, B and C* represent the values of VSI, reliability and LSF denoted as equation below.

$$A = \frac{VSI_{base}}{VSI_{EV}} \tag{9}$$

$$B = W_{COI} * \frac{COI_{EV}}{COI_{base}} + W_{EOI} * \frac{EOI_{EV}}{EOI_{base}} \tag{10}$$

$$C = \frac{LSF_{EV}}{LSF_{base}} \tag{11}$$

Where COI and EOI denotes the customer-oriented indices: SAIFI, SAIDI, CAIDI and energy-oriented indices AENS respectively. VSI_{EV}, COI_{EV}, EOI_{EV}, and LSF_{EV} are VSI, reliability and LSF after the allocation of charging stations. VSI_{base}, COI_{base}, EOI_{base}, and LSF_{base} are base value of VSI, reliability and LSF before the allocation of charging stations. The threshold limit for placing charging stations denotes by $EVPI_T$ is expressed as in equation below;

$$EVPI_T = BRI_T(\frac{W_{VSI}}{W_R} + \frac{W_{LSF}}{W_R}) \tag{12}$$

BRI_T is the threshold limit of BRI for buses. In the reliability index approach, the effect of distribution reliability indices is more critical than voltage stability and power loss.

Table 1 Electric vehicle CS input parameter

S.N	Parameters	Values
1	EV charging current	200A
2	Battery capacity	Nexon, Hyundai Kona,BYD, MG
3	N_{slot}	5
4	Grid frequency	50Hz
5	Grid voltage	0.433KV
6	K	1.1
7	*cosØ*	0.95

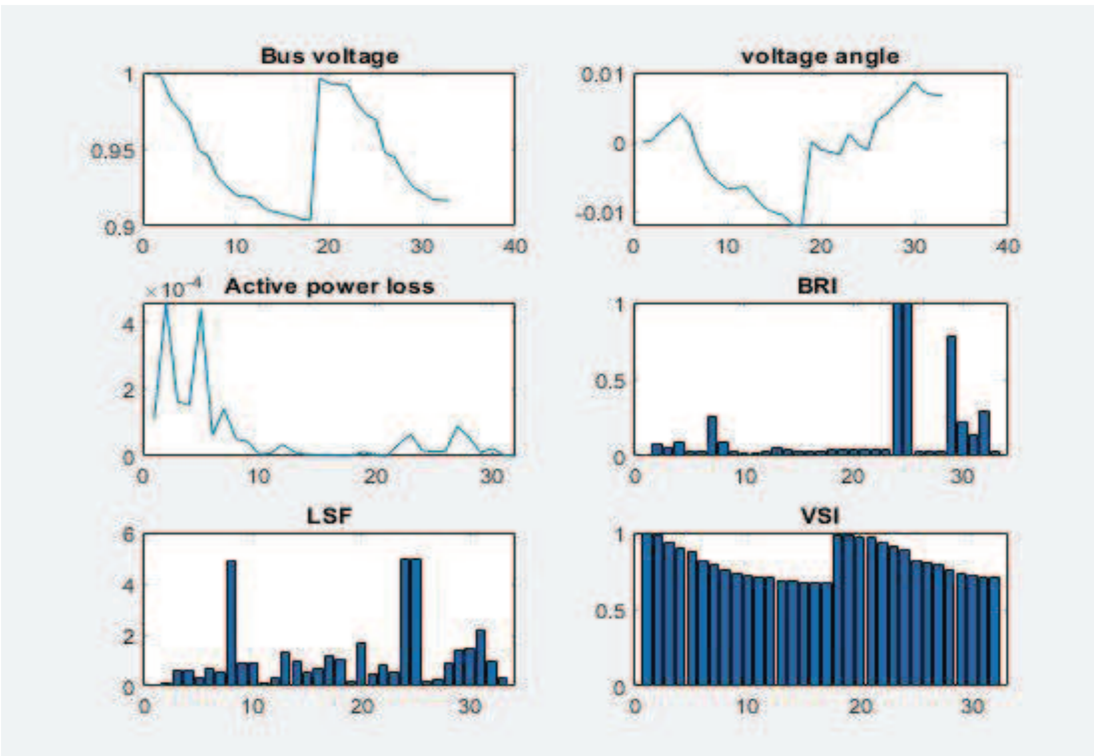

figure 1 *Base value of bus voltage, voltage angle, power loss, BRI, LSF and VSI of IEEE 33 bus system*

IV. V2G CONTROL STRATEGY

Electric vehicle Charging/discharging based upon the initial state of charge (SOC), real time electricity pricing, charging requirement of vehicle and daily travel distance by vehicle [21]. The analysis is carried for whole day. Analysis during peak hour only do not give exact reliability. ENS of the system is calculated for whole day [22]. In the table below, coordinated charging and discharging strategy is presented. Three test cases are assumed.

Table 2 Cases for charging/discharging

Test cases	strategy
Case I	10% charging only
Case II	70 % charging only
Case III	V2G

In case I, no discharging takes place. Vehicles are assumed to travel between home and office. No more charging required by vehicle. To travel 50 km only 10% of total charge is enough. Only 3 hour of charging is sufficient. So, there is no need to follow any charging schedule. Randomly charging vehicle is assumed.

In case II, Assumed the vehicles have to travel long distance. It maximum discharges it's 70% of charging for smooth operation of battery. All the vehicle cannot be in such mode. But this condition assumed to make worst case scenario.

In case III, Vehicles are performed V2G. scheduled charging and discharging because electricity price is high during peak hour and low during off-peak hour. Table 3 shows detail strategy for charging and discharging in all these three cases.

V. RESULT AND DISCUSSION

Impact of charging station and V2G on voltage profile

Table 4.1 shows the voltage of all the buses for the base case as well as after placing charging stations for all case mentioned in table 3.0.1. The voltage at Bus 11 in case 2 is less than the voltage at base case but it is within acceptable range. However, In case 4 the voltage at bus 11 is 0.6898 and bus 15 is 0.6243. These values were not within the tolerance limit.

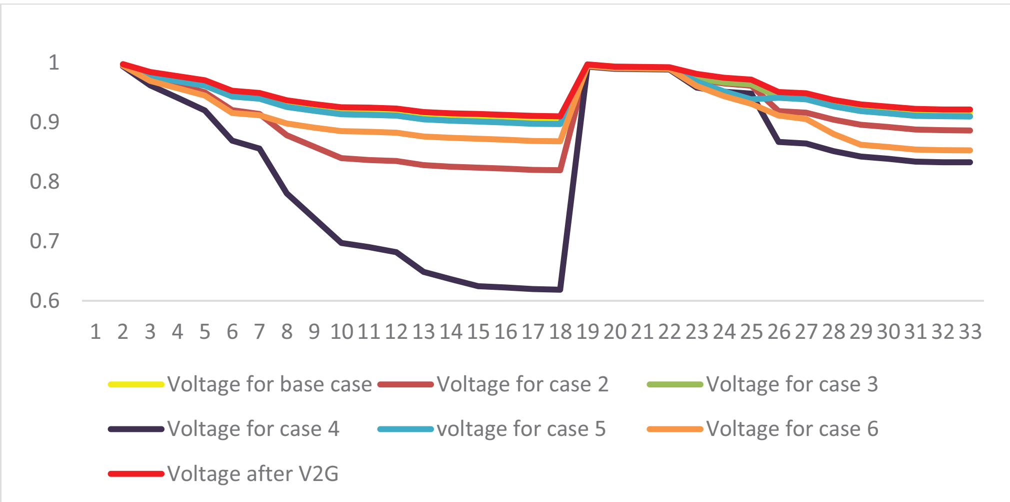

figure 2. Voltage profile after placing CS in different test cases during peak load time

Impact of Charging station load and V2G on VSI

The value of VSI is calculated using equation no 14. Table 4.1.2 shows the report of the VSI

Table 3. V2G control strategy

Time	Total power(MW)	Scheduled chg/Dhg	Charging-3KW-100	unscheduled 10% charging	Result p	70 % charging daily	Result p	Discharge-2.5-150	Resultant P
1	1.2	C	0.294	0.02	1.22	0.1063	1.3063	0	1.494
2	1	C	0.294	0	1	0.1063	1.1063	0	1.294
3	1	C	0.294	0	1	0.1063	1.1063	0	1.294
4	1.2	C	0.294	0	1.2	0.1063	1.3063	0	1.494
5	1.2	C	0.294	0	1.2	0.1063	1.3063	0	1.494
6	1.5	C	0.294	0	1.5	0.1063	1.6063	0	1.794
7	2.1	C	0.294	0.08	2.18	0.236	2.336	0	2.394
8	2.8	D	0.0294	0.08	2.88	0.236	3.036	0.294	2.5354
9	2.4	0.9D	0.0294	0.08	2.48	0.236	2.636	0.2646	2.1648
10	2.6	0.5D	0.0294	0	2.6	0	2.6	0.147	2.4824
11	2.7	0.5D	0.0294	0.02	2.72	0.081	2.781	0.147	2.5824
12	2.6	D	0.0294	0.02	2.62	0.081	2.681	0.294	2.3354
13	2.6	D	0.0294	0.02	2.62	0.081	2.681	0.294	2.3354
14	2.6	D	0.0294	0	2.6	0.081	2.681	0.294	2.3354
15	1.7	C	0.294	0	1.7	0.081	1.781	0	1.994
16	2.6	D	0.0294	0	2.6	0.081	2.681	0.294	2.3354
17	2.6	D	0.0294	0	2.6	0.081	2.681	0.294	2.3354
18	2.5	N	0.0294	0	2.5	0	2.5	0	2.5294
19	2.6	0.5D	0.0294	0	2.6	0	2.6	0.147	2.4824
20	2.7	D	0.0294	0.08	2.78	0.236	2.936	0.294	2.4354
21	2.4	D	0.0294	0.08	2.48	0.236	2.636	0.294	2.1354
22	2	C	0.294	0.08	2.08	0.236	2.236	0	2.294
23	1.5	C	0.294	0.02	1.52	0.1063	1.6063	0	1.794
24	1.8	C	0.294	0.02	1.82	0.1063	1.9063	0	2.094

calculated for all the cases. It is observed that VSI at bus 29 in case 6 is 0.5743. This is very low and is unacceptable. Thus, placement of charging station at the weakest bus caused severe degradation of the voltage stability.

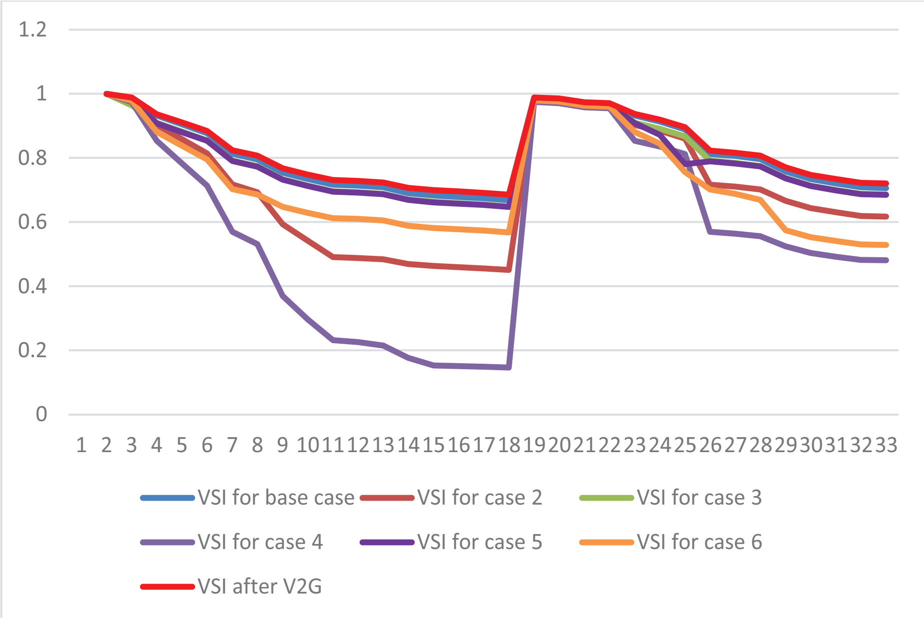

figure 3. VSI after placement CS in different test cases during peak time

Impact of CS load and V2G on reliability.

The impact of charging station on reliability is analysis for all the six cases in table 3.0.1. In order to calculate the reliability, the data of failure rate, repair rate and outage duration of the system for IEEE 33 bus [8]. Table 4.2 shows the reliability indices of all the case. For case 2, SAIFI is more than the base case but less than the critical value of SAIFI, Similarly for SAIDI, CAIDI and AENS. For case 5 and 6, indices value is very large that cannot be tolerated.

Table 4. Impact of CS and V2G on reliability

case no	SAIFI	SAIDI	CAIDI
1	0.098237	0.504788	5.13845
2	0.112165	0.551215	4.914306
3	0.116034	0.638266	5.500667
4	0.126094	0.64407	5.10787
5	0.184086	1.001808	5.442061
6	0.426959	1.136738	2.662405
After V2G	0.090463	0.464839	1.737955

Impact of charging load and V2G on power Loss.

The value of power loss increases after the placement of charging station. For case 2, the value of power loss is only 0.002029 which is very low. For case 5 and 6 value of power loss is 0.00365 and 0.0079284 respectively. These value are very high compared to base case. LSF is directly depends on power loss. Power loss increases as charging stations distance from the origin increases represented by figure below. power loss for case 2 is low and case 7 is very high. With V2G power loss is even lower than base case is 0.0017 p.u.

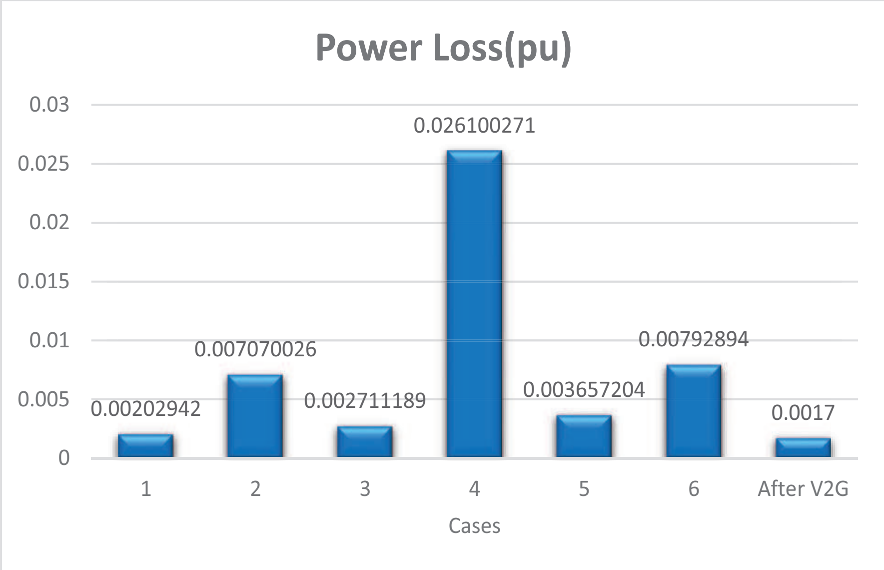

Figure 4. Impact of CS and V2G on loss of the system

EVPI Evaluation For all the cases

The load in the charging station is not fixed. It is peak during 11-1:00 AM and there is no load during night time. Then how can we analysis the system considering peak load only although at that time charging station load is very low. Due to lack of time, we have broken the load in four parts of the day.

Table 5. Load distribution based on time

Time	IEEE load	CS load (KW)
00:00- 6:00 AM	60% of peak load	0.8
6:00-12:000 AM	Peak load	700
12:00-18:00 AM	80% of peak load	1297
18:00-24:00 AM	Peak load	393

Table 6. EVPI of the whole day

time	Case 2	Case 3	case 4	case 5	case 6
00:00-6:00	0.8850049000	0.8659811000	0.8860355000	0.8704980000	0.8742879000
6:00-12:00	2.738558000	1.966855000	2.752204000	1.436978000	1.516410000
12:00-18:00	4.640993000	3.057735000	5.555524000	2.023221000	2.473329000
18:00-24:00	1.882748000	1.479254000	1.803292000	1.197548000	1.176285000

From the above table 5.3 it can be seen that value of EVPI is lowest in Case 5 in peak time of day. So, it is the best optimal placement of charging station. During no load period, EVPI is lower is Case 3. Hence optimal placement is at bus 25.

OPTIMAL PLACEMENT USING GA

Charging stations are placed in the distribution network based on EVPI index. Genetic algorithm (GA) is used for optimally placement of charging station. For single charging station the optimal locations is Bus 24.

VI. A CASE STUDY IN BANESHWOR FEEDER.

Nepal Electricity Authority (NEA) has set up 51 fast charging stations in different parts of country. It has planned more than hundred to be set up till the end of 2080 B.S. This charging station takes 1hr to charge the vehicle fully. The real system data of Baneshwor feeder is considered for the analysis. It also includes 24 distribution transformers. The scheduled and unscheduled outages of this section for the past 1 year (September 2022- September 2023) is taken for the analysis. The diagram of feeder shown in figure 5. The yellow dotted spot represents the transformer.

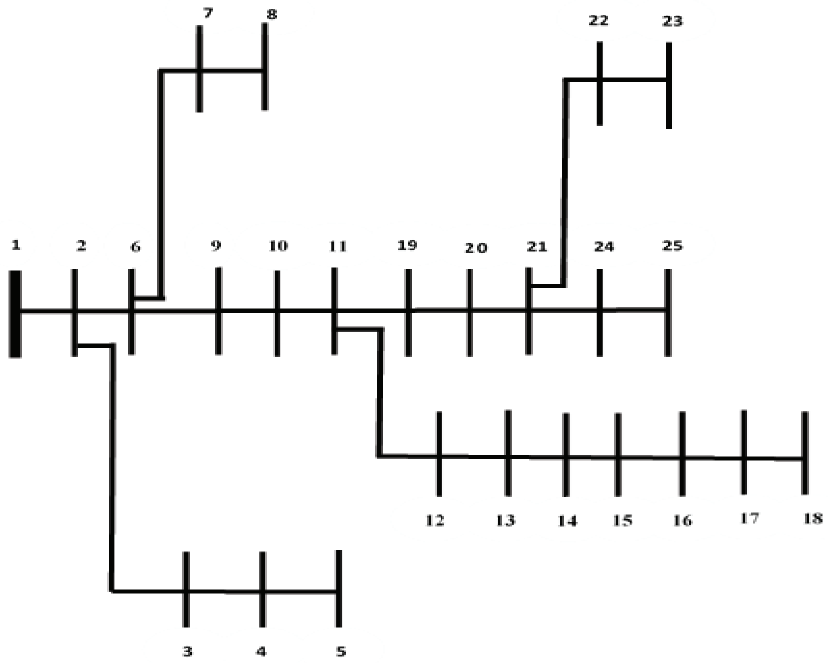

Figure 5. single line diagram of Baneshwor feeder.

Table 7 Test case condition for baneshwor feeder

Case no.	Description	Increase in load (KW)	No of charging column
1	Base load	---	--
2	EVCS at Bus 3	120	2
3	EVCS at Bus 8	120	2
4	EVCS at Bus 3 and Bus 6	240(120 KW each)	4
5	EVCS at Bus 12	120	2
6	EVCS at Bus 12 and Bus 23	240(120 KW each)	4

IMPACT OF CS LOAD AND V2G ON VOLTAGE PROFILE OF BANESHWOR FEEDER

figure shows the voltage of all the buses for the base case as well as after placing the charging stations for all the cases mentioned in table 3. The voltage of bus 3 for case 2 is 0.998968. Thus, the magnitude of the voltage for bus 3 in base case 2 is 0.9989 less than the base case voltage, but still within the acceptable range. The lowest voltage occurs at bus16 in case 6. Voltage after V2G integration increases.

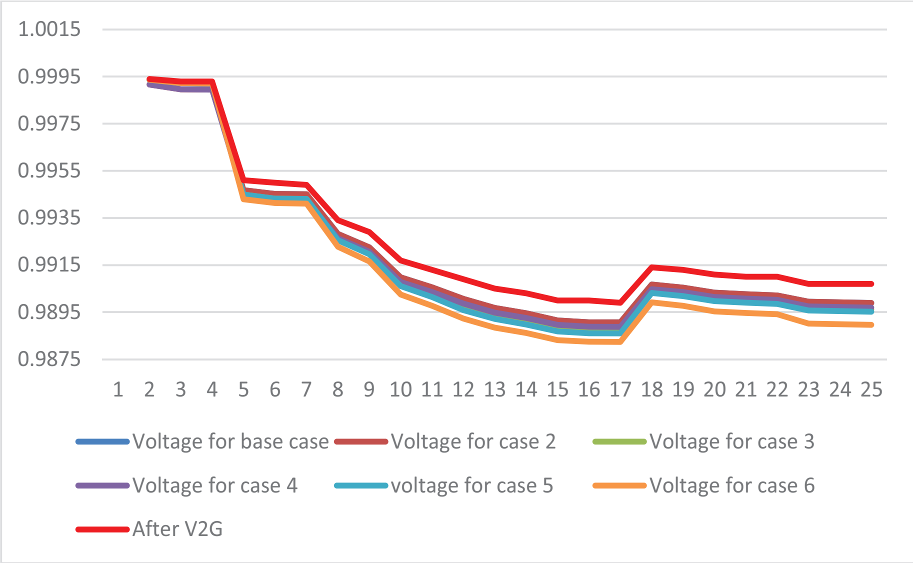

figure 6. Impact of CS and V2G n voltage profile of Baneshwor feeder

Impact of CS load and V2G on VSI for Baneshwor feeder

Figure 6 shows the VSI of all the buses of Baneshwor feeder for the base cases as well as after placement of charging station for all the cases mentioned in table 3. The result of VSI is similar to the voltage profile.

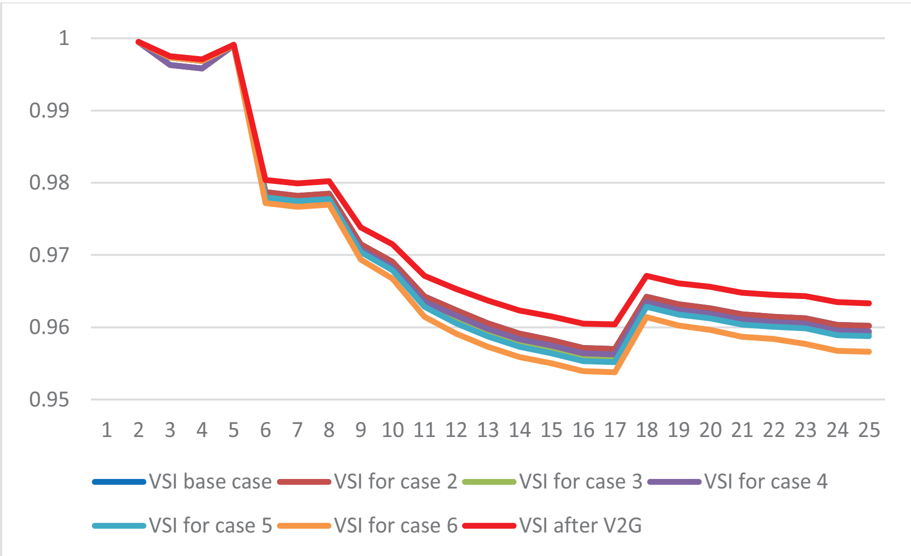

figure 7. impact of CS load and V2G on VSI for Baneshwor feeder

Impact of CS load and V2G on reliability of Baneshwor feeder.

Table 4 shows the impact of placement of charging station on different reliability indices. The value of SAIFI for case 2 is 2.126025. This value is more than the base case but less than the critical value. Similarly for other indices SAIDI, CAIDI. It is observed that for case 5 and case 6 indices value is lowest but can be tolerated. For the placement of charging station bus with good reliability indices should choose.

Table 8 Impact of CS load and V2G on reliability of Baneshwor feeder

case no	SAIFI	SAIDI	CAIDI
Base case	2.090352	0.936256	0.447894

2	2.126025	0.954092	0.448768
3	2.161697	0.972523	0.449889
4	2.161697	0.971928	0.449614
5	2.200613	0.973043	0.442169
6	2.30763	1.019059	0.441604
After V2G	1.90731	0.854272	0.447894

EVPI Evaluation of Baneshwor feeder after placing CS in different test cases:
Figure 7 shows graph of EVPI of Baneshwor feeder after placement of charging station with all the test cases mentioned in the table 3. Figure shows that the EVPI for different test cases is within the threshold value that means the network has steady operation even after the establishment of EV charging loads. Hence, Large number of charging station can be penetrated at strong buses.

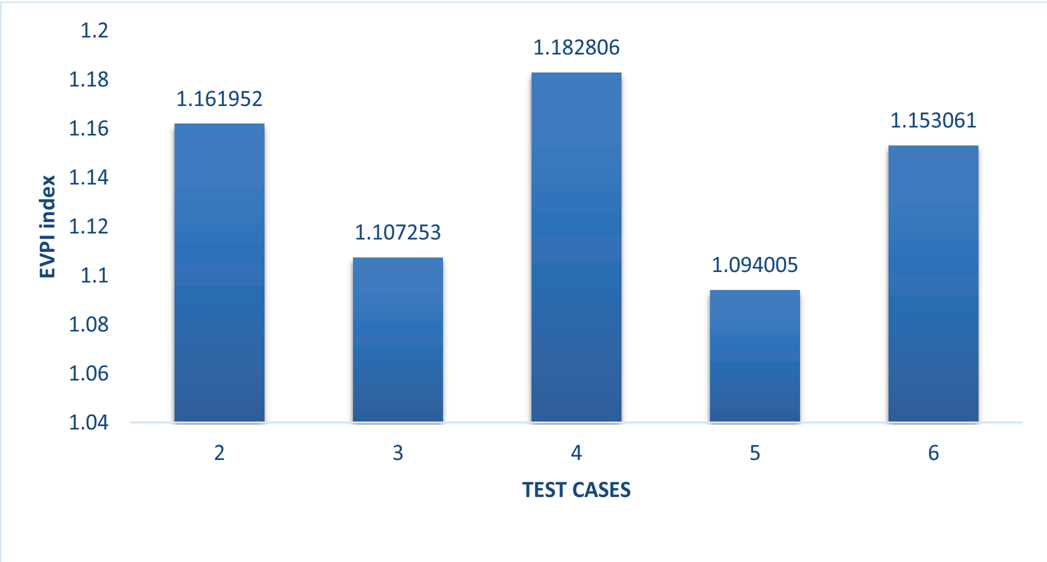

figure 8. EVPI for Baneshwor distribution feeder

The optimal placement of charging station in Baneshwor distribution network using Genetic algorithm (GA) is bus no 3 and 5.

Integration of V2G in Baneshwor feeder
The 24 hr load proile of Baneshwor feeder is shown in figure 8. This is average data of month jun/July 2023. This load is proportionally distributed to all the 25 buses of this feeder. Tata nexon and BYD vechicle parameter is considered. 100 vehicles assumed in the feeder. In first case, vehicles are charging only 10 % of full battery capacity. Vehicles are generally used for travelling from office to home. Only 50 Km of travelling is considered. Energy used for travelling is 5Kwh. So user do not follow scheduled charging. In case 2, vechicles charging 70% of full battery capacity. Energy used for this charging is 28.334 Kwh. In case 3, during peak hour, vechicle discharges and during off peak hour vehicles are charging. Charging and discharging strategy is shown in table 1.with and without V2G reliability is carried out for 24 hour load flow.in table 5, failure rate and repair rate of all bus is calculated during peak load of all the three condition is calculated. In table 6, reliability parameter is calculated. It shows reliability of system decreases as charging in the system increases.
In the figure 4.10 ENS for the base case is 46.689Mwh/Yr. when charging station is added in the system by 10 % it increases to 47.25053Mwh/Yr. and 49.3402Mwh/Yr. when charging by 70% EV. With integration of V2G ENS decreases to 47.2118Mwh/yr. it is lesser than 10% and 70% charging but higher than base case.

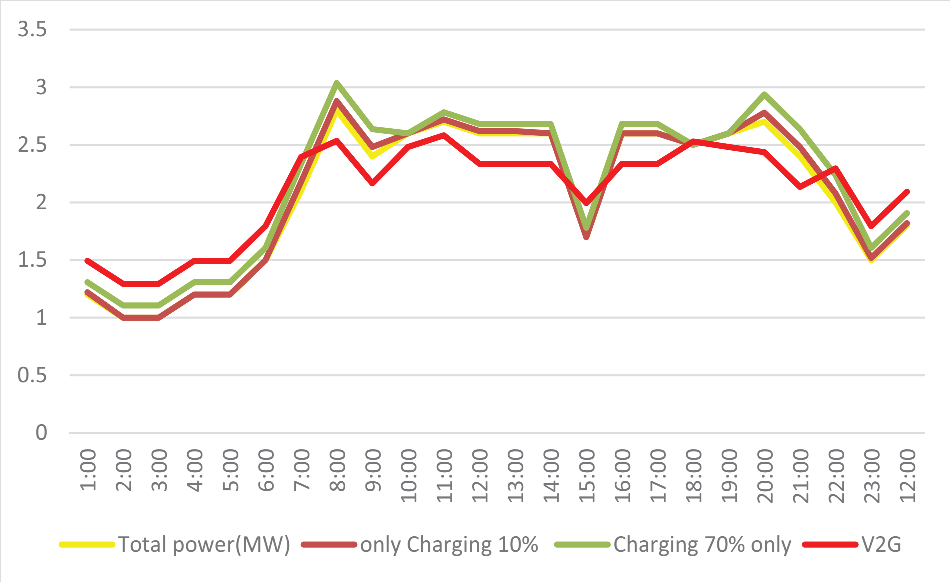

figure 9. Load curve of Baneshwor feeder with all condition

Table 9 Reliability evaluation for all the cases.

Reliability indices	Base load	10% Charging only	70% charging only	After V2G
SAIFI	2.0906	2.15	2.26685	1.893
SAIDI	0.9364476	0.9632	1.01537	0.84795
CAIDI	0.4479	0.448	0.447921124	0.447939778
ENS(Mwh/yr)	46.68913502	47.25053	49.340217	47.2117914
AENS	0.017343661	0.017552203	0.018328461	0.017537813

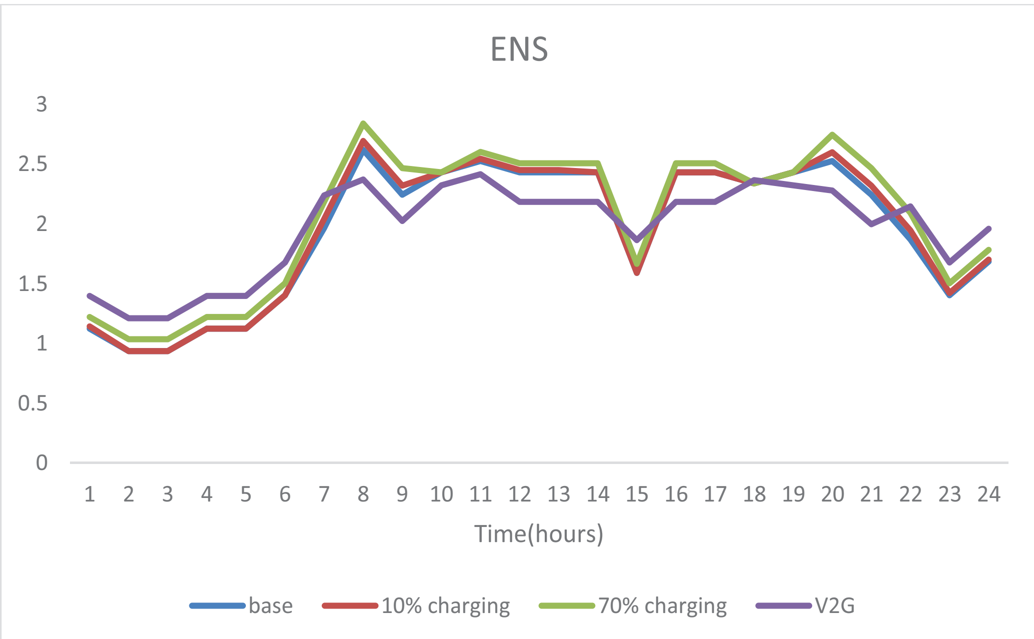

figure 10. ENS graph of Baneshwor distribution system

VI. CONCLUSION

Owing to EV penetration, it is recommended to place the EV charging stations at strong buses within a threshold limit. The maximal threshold limit is decided by EVPI. Thus, the intended approach focuses on charging station allocation of any distribution system without a physical restructuring of the network upholding the mathematical formulation of EVPI threshold limit and hence maintaining the overall system performance. Power management strategies incorporating the V2G feature of EV for the performance improvement of a distribution network reliability. Reliability decreases as number of vehicles increases. When V2G is applied in the system reliability (SAIFI, SAIDI) increases even better than the base case. These contributions will aid in making informed decisions regarding infrastructure planning, grid management, EV integration strategies and V2G integration.

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